MAKING COP26 COUNT

How investing in public transport this decade can protect **our jobs, our climate, our future**

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Methodology for jobs modelling for The Future is Public Transport COP briefing

The methodology for estimating jobs creation from public transport is adapted from previous work undertaken by C40 to estimate the jobs impacts of climate action[1]. The process entails deriving GHG emission trajectories for transport, establishing the investment required for the transport climate actions required to achieve these trajectories, and calculating the employment impacts of this investment.

A   Part A: Methodology for GHG emission trajectories
A.1   Introduction and overview of method

This section presents the methodology adopted for quantifying the emissions trajectories under a Business as Usual and Green Recovery scenarios.

The aim of this analysis was to produce GHG trajectories from 2021 (hereafter referred to as the base year) to 2030 under the scenarios listed above.

The Green Recovery represents a scenario in which COVID-recovery stimulus funding supports C40 cities to invest in transport sector climate action that prioritises rapid creation of employment and ensures that C40 cities transport systems are on track to limiting warming to 1.5°C.

The Business as usual (BAU) scenario represents the level of investments that is expected to maintain and expand existing transport infrastructure in cities in accordance with population and GDP growth in cities, without additional climate actions that reduce urban emissions in line with Paris Agreement commitments. Note that the BAU scenario does not take into account potential advances in technology or changes in policy. Nor does it account for any policy change as a result of stimulus funding. In effect, it is a pre-COVID-19 BAU scenario. While some individual BAU investments, for example in expanded transit networks, might contribute to reduced emissions, the overall effect is marginal compared to that required to be on track with 1.5°C.

The modelling of GHG trajectories was undertaken with C40 Cities' in-house modelling tool Pathways. The Pathways Tool is a customisation of the CURB tool that addresses the specific needs of C40's Climate Action Planning (CAP) programme. Specifically, the tool assesses the impact of climate mitigation strategies in the context of C40 cities around the world. In practical terms, the tool allows the user to set penetration levels of climate actions across key sectors, namely Buildings, Electricity Generation, Transport, Waste and Industry. Listed in Table A-1 below are the climate actions within the Transport sector, the only sector reported in this analysis.

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[1] https://www.c40knowledgehub.org/s/article/Creating-local-green-jobs-the-United-States-Italy-and-South-Africa

Table A-1 Overview of the transport sector climate actions modelled in Pathways

Climate Action Area	Climate Action modelled in Pathways
Public transport	Shift away from: • Passenger Automobiles • Motorcycle • Taxi • Moto-Taxi To: • Microbus • Minibus • Bus – Standard • Bus – BRT • Subway • Light Rail • Commuter Rail
Walking & Cycling	Shift away from: • Passenger Automobiles • Motorcycle • Taxi • Moto-Taxi To: • Bicycle • Walk
Fuel Switch / Efficiency	Fuel Efficiency; Shift away from fossil fuels to low carbon fuels (electricity, biodiesel, hydrogen).

The Pathways model calculates emissions in three time periods based on stipulated penetration levels. As a result, to produce emission trajectories, it was necessary to extrapolate between the data points of the different time periods.

The model cities used for this analysis were based on pre-populated baseline data within Pathways. This baseline data was collected under C40's CAP programme.

The bulk of scenario development was focused on the Green Recovery, for which the penetration levels of the different climate actions in 2030 were determined for each modelled city. The approach and sources for these penetration levels are discussed in more detail in Section A.2.2 Green Recovery Scenario.

As indicated above, the key period of interest for the emissions trajectories was 2020 to 2030. Given that the baseline data within Pathways for the model cities varied between 2014 and 2017, it was necessary to develop an approach to normalise to the base year of 2020. The high-level approach was to adopt the emissions in 2020 according to the BAU scenario within Pathways. It is recognised that this approach may underestimate the emission reduction achievements of the model cities.

A.2   Emissions trajectory scenarios methodology
A.2.1 Business as Usual (BAU) scenario

The BAU is a scenario that projects activity and emissions growth using population and economic changes as the primary growth drivers. Note that the BAU scenario does not take into account potential advances in technology or changes in policy. Nor does it account for any policy change as a result of stimulus funding. In effect, it is a pre-COVID-19 BAU scenario. Within Pathways, the specific growth drivers and growth rates applied depend on the emissions sub-sector involved.

In the transport sector, population and GDP change is applied using annual growth rates from the base year to the selected forecasted horizon years - 2021 and 2030.

Importantly, the BAU scenario does not include any technological changes or reflect the influence of any national, regional, local policy or market transformation influence. All technology or systems assumptions are held constant in the BAU scenario.

For the purposes of this analysis, the annual growth factors were obtained from the pre-populated baseline data input as part of C40 Cities CAP technical assistance programme with individual cities (applicable for Houston) or based on population growth factors for other cities (notably Milan, London and Jakarta)

A.2.2 Green Recovery scenario

When developing the Green Recovery scenario for each of the four model cities, we first considered whether prior analysis for model cities aligned with a Deadline 2020 trajectories (developed by prior analysis to represent 1.5°C compliant trajectories[2]). We took into account the different regional emission trajectories set out in C40's Deadline 2020 report (namely, the Steep Decline, Accelerated Peak, Steady Decline and Slow Peak). If a model city's Pathways trajectory emitted more than its 1.5°C -compliant target trajectory, we increased the scale of ambition, assuming that this would be supported by global stimulus focused on climate and equity. Once the model city's Pathways trajectory across all sectors had met its Deadline 2020 emissions targets, we created its Standard Recovery scenario, setting the level of climate action and associated investment needed to prevent it from exceeding the level of emissions allowed by a 1.5°C trajectory.   Due to resource and time constraints, London and Jakarta used simplified version of the pathways modelling that only included transport actions. Scenarios were created based on accelerating ambition in existing transport strategies.

From a Pathways model perspective, this relied on inserting or modifying the penetration levels across climate actions included within Pathways and ensuring that their combined effect meant the city emissions trajectories aligned with their Deadline 2020 trajectories. The penetration levels were set in one target year – 2030.

As far as possible, the penetration levels were meant to be regionally representative. The sources for enhanced penetration levels varied based on the scenario analysis undertaken to date for the cities analysed. Broadly, there were two main sources, shown by order of preference:

- Prior analysis by the city or comparable cities (e.g. Athens was used to inform Milan) on feasible and ambitious penetration levels
- Penetration levels derived from analysis by McKinsey on the level of action required by C40 cities according to distinct city typologies, in order to meet the global 1.5°C target.[3]

The penetration levels were reviewed in detail by sector experts within C40 to ensure these were regionally representative. Where anomalies were identified, the penetration levels were revised according to the recommendations of C40 sector experts or further research was undertaken. The latter was particular important for European cities modelled, such that penetration levels in 2030 were based on EU-wide projections for the following climate action areas:

- clean energy[4]
- mode shifts to public transport[4]

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[2] For more detail on this approach see the methodology document found here: https://www.c40.org/other/deadline_2020

[3] The McKinsey Center for Business and Environment, 2017

[4] International Renewable Energy Agency and European Commission, 2018

● EV market share[5]

A.3 Limitations of methodology for GHG analysis

The key limitations of the GHG analysis are described below:

Reliability of baseline activity data could not be confirmed. In some instances, the data was not at the required level of detail or was entirely missing. This affected the reliability of emissions projections under the Green Recovery scenarios. For example, certain cities lacked a breakdown of private road vehicle data according to passenger automobiles, medium duty truck, light duty truck etc., and as a result the penetration levels for mode share shifts, fuel switch and fuel efficiency might be distorted.

Overestimation of BAU and base year (2020) emissions by relying on growth factors combining population and GDP growth only. This approach was used due to limitations in available data and resources, however they could result in inflated emissions given that many of the cities may have introduced climate action policies to date, as well as due to major trends such as energy intensity reductions or shocks such as COVID.

Reliability of penetration levels varied between the cities' analysed. As seen in the preceding section, the penetration levels were based on different sources, with the prior analysis by the city under the CAP programme being the most reliable. The penetration levels from the McKinsey analysis required interpretation of broader climate actions to reach the level of detail within the Pathways model.

Applicability of regionally representative penetration levels to specific cities given their unique emissions profile and context. In some instances, the cities showed anomalous profiles within sectors e.g. the carbon intensity of the grid. The superimposition of regionally representative penetration levels of climate actions in 2030 and 2050 to these cities could lead to overly (or under) ambitious climate actions. The feasibility of the penetration levels was not tested for all cities and climate actions, but rather reflects what is required to meet the 1.5°C target.

Reliability of the projection of infrastructure and systems within cities in developing economies under the BAU and Green Recovery scenarios. This could affect a number of sectors. For instance, in the transport sector, the number of trips per capita or the average distance travelled was not assumed to change whilst this could also evolve with income. The impact on results is that the growth in emissions may be underestimated.

In some model cities, the cumulative emissions between 2021 and 2030 of the standard Green Recovery scenario slightly exceeded the 1.5°C compliant (Deadline 2020) scenarios. The level of exceedance was marginal, and 2030 emissions were on track for all cities. Further analysis could be undertaken to ensure the Green Recovery scenario exactly matches the Deadline 2020 trajectory with regard to cumulative emissions.

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[5] Ricardo Energy and Environment, 2016

B   Part B: Methodology of investment costs

B.1   Introduction and overview of method

This section presents the methodology for quantifying the public transport expenditures associated the Green Recovery. The Green Recovery scenario expenditures were built from costing the different public transport infrastructure and vehicles projected to be present within the city analysed, by 2030.

B.1.1 Overview of bottom-up analysis for BAU and Green Recovery scenarios

Public transport expenditures for the Green Recovery scenarios were based on the city's baseline public transport profiling data and changes to these according to the corresponding scenario modelled in Pathways.

Expenditures calculated covered new investments in public transport infrastructure, vehicles and rolling stock, replacement and rehabilitation of infrastructure, vehicles and rolling stock as well as annual operation and maintenance costs. Cost benchmarks for these were sourced from existing literature. The specific infrastructure and systems for which costs were quantified are described in more detail within the section C.2.

Where possible, the capital costs included commissioning and installation however it was not possible to verify this for all data collected. Financing costs may at time also be included within the capital costs.

All costs were reported in USD for the year 2020. Cost estimates collected in foreign currencies were converted to USD using three-year averages to avoid distortions from short term fluctuations.

On the whole, historical cost data was normalised to 2020 using the national consumer price index rates appropriate to the city in question.[12]

It is recognised that a key limitation of the general approach is that the effect of learning rates, which reduce technological costs, was not accounted for. These may be significant for certain technologies featured within the Green Recovery scenario, notably electric buses.

In general, investment cost quantification was tailored to model cities by obtaining the following:

- Baseline sectoral profiling data from Pathways and other sources, where required
- Collecting city specific cost benchmarks. These were more likely to be available at state, national, or regional level (i.e. Europe, North America etc.).

A data quality robustness scoring matrix (shown below) was developed to assess the robustness of data collected (outside of data extracted from the city Pathways models). Robustness was assessed based on the source of the data, the geographical overlap, the proximity of reporting

year to 2020 and how well matched the data point was to that being collected. The latter was important where data may have been provided at an aggregated level e.g. sector rather than relating to the specific system or infrastructure of interest. No data that had a score of zero was utilised in this study.

Table B-1 Data Quality Robustness Scoring

	Not fit for purpose (scoring of 0)	Low (scoring of 1)	Medium (scoring of 2)	High (scoring of 3)
Source of data	Cannot determine author / credibility of author	Not published by any of the prior options	National non-government organisation / company or manufacturers data	Academic / government / internationally recognised organisation
Geography	n/a	Global / regional / comparable country or city	National or province within which city is found	City specific
Reporting year	Any years before 2002[1]	2002-2011 (up to 17 years from reporting year)	2012-2016 (7 years from reporting year)	2017-2020 (within 3 years of reporting year)
Data match	Data not possible to match to system / infrastructure	Data aggregated and difficult to match to system / infrastructure (e.g. requiring multiple assumptions)	Data sufficiently disaggregated to match the specific system / infrastructure (may require a single assumption)	Data for specific system / infrastructure

In the case of cost data, the benchmarks, if collected in a foreign currency or reporting year prior to 2020, were revised as described in the preceding section.

In the case of city profiling data, the data was manipulated for use in quantifying costs according to the following approach:

- Data collected at geographic scales different to the city were converted to city scale based on population or geographic area depending on the data of interest. For example, the number of vehicles according to different types was often collected for the country as a whole and converted to city scale using a pro rata of population. On the other hand, where length of commuter rail was collected at metropolitan scale, this was converted to city scale using a pro rata of area.

- Data that did not match the system/infrastructure was converted to the correct data point based on assumptions. For example, if data was available for passenger vehicles

B.1.2 General limitations and recommendations for further development

Firstly, it is worth noting that inaccuracies within the Pathways modelling would directly impact on investment costs given that the Pathways is a key source of input data for these sectors.

Reliability of input data per sector varied across cities. The transport sector was the most vulnerable because it depended on many different input data such as baseline transport infrastructure and vehicles. The accuracy of investment costs is directly correlated to the accuracy of these input data.

Risk of overestimating infrastructure needs according to the scenarios. An important limitation emerging from the approach was that projections of infrastructure and system requirements were based on theoretical relationships. To address this risk in the transport sector, globally applicable limits or caps were adopted. Nonetheless anomalies in the expansion of transport infrastructure were identified and in one instance, the cap was revised to reflect the country context.

Risk of overestimating investment costs due to assumed best practice in the replacement rate or rehabilitation of infrastructure and systems as well as annual O&M practices. In all sectors, it was assumed that systems and infrastructure would be replaced according to their respective global average or best practice useful life, as well as have regular O&M services. In reality, these may vary according to regions and cities. Certain anomalies were investigated further, and adaptations made to use locally representative useful life estimates. The impact of this limitation is likely to be most significant for developing economies where useful life and O&M servicing may be longer and more irregular than the best practice respectively, leading to an overestimate of costs.

Accuracy of investment cost benchmarks varied between cities due to challenges in obtaining local data. In general, costs were either differentiated according to advanced and developing economies or exclusively drawn from advanced economies such as the US or Europe. The level of inaccuracy would be greatest on investments that depend highly on local labour (e.g. construction) and least for products with global supply chains or which are highly traded (e.g. vehicles). On the whole it was not possible to account for the effect of local taxes and or subsidies on investments.

Overestimates associated with application of the inflation rate to historical prices. As indicated earlier, this risked overestimating costs where technologies are still developing or extending their market allowing for economies of scale. The impact may be significant for certain technologies featuring within the Green Recovery scenario, notably electric vehicles, heat pumps and renewable energy generation systems. More generally, the change in costs of different investments is more or less correlated with national inflation rate and could therefore lead to discrepancies with observed costs. A conservative adaptation to the inflation rate was adopted for

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one model city, given that its host country had experienced anomalously high inflation that could not be considered representative of future inflation.

Oversimplification of the rate of investment. The CAPEX and O&M investments were assumed to occur over different time periods, with the former occurring in a shorter period as relating to a stimulus package as opposed to ongoing operation and maintenance costs. Additionally, the Accelerated and Slow recovery was different from the Standard by shortening and lengthening the period for capital investments. This is a major oversimplification of capital investments schedules given that these are dictated by the complexity of the investment type affected by local planning processes, regulations and supply chain factors (e.g. shortage of skills). The results are meant to illustrate the possible dynamics of accelerating or slowing the recovery investments, as well as to calculate total jobs from the results in job years. Total jobs refer to the number of full-time jobs available in a given year. For example, five job-years in one year creates five total jobs, five job-years over five years creates one total job.

Recommendations for further development

In the future, the modelling of investment costs could be improved in the following ways:

1. Investment cost modelling undertaken in tandem with baseline data collection for Pathways. This would improve the consistency of data and assumptions between the GHG and cost modelling of GHG, avoiding discrepancies caused by mismatch.
2. By increasing the investment types for which costs were modelled. In each sector (described under sector specific limitations below), certain costs were excluded and could be incorporated in future iterations.
3. Expansion and refinement of public transport infrastructure caps to reflect limitations in the expansion of public transport infrastructure whilst making these more locally specific. In future, it would be useful to develop caps for typologies of cities such that the caps are better matched to the city context, e.g. low-density cities would have more stringent limits on rail infrastructure per m2.
4. Addition of locally applicable useful life assumptions per city such that the replacement or rehabilitation rate of infrastructure and systems is more accurate.
5. Local representativeness of cost benchmarks improved either by obtaining local cost data or otherwise using local cost factors which reflect the impact of local wages on overall costs.
6. Review of inflation-based approach to normalising costs to 2020. Learning rates could be incorporated as well as certain costs excluded from application of consumer price indices (CPI) where research indicates these are not appropriate.
7. Introduction of sensitivity analysis within the workbooks. This would allow users to appreciate the sensitivity of outputs to inputs and enable prioritised cross-referencing and sense-checks of these inputs. This could improve the accuracy of the results and inform future research and development of the modelling.

B.2   Methodology and limitations for estimating transport expenditures
B.2.1 Overview of transport expenditures estimated

The transport expenditures broadly covered any new investments in infrastructure and vehicles across all mode types, as well as their replacement over time and annual fixed O&M. In order to

match the employment multipliers from the I3M, only costs relating to sustainable transport interventions were used e.g. expenditure on public transport infrastructure rather than internal combustion engine (ICE) vehicles. Note also that the employment analysis related only to new investments in sustainable transport infrastructure or vehicles, not those relating to rehabilitation / replacement. Table B-2 below gives the full breakdown of transport costs estimated and their mapping to employment multipliers described in part C.

Whilst costs of private vehicle electrification and cycling infrastructure were provided and included within the modelling, the figures were not utilised in the briefing

Table B-2 List of investment costs quantified under transport sector

Expenditure Group	Expenditure Item	Mapping to Employment Multipliers
Bus infrastructure	CAPEX of new segregated BRT corridors	BRT job multiplier – construction phase
	CAPEX of reconstructed segregated BRT corridor	
	O&M cost of segregated BRT corridor	BRT job multiplier – operational phase
Rail infrastructure	CAPEX of new LRT	Rail job multiplier – construction phase
	CAPEX of rehabilitated LRT route	
	O&M cost of LRT route	Rail job multiplier – operation phase
	CAPEX of new HRT	Rail job multiplier – construction phase
	CAPEX of rehabilitated HRT route	
	O&M cost of HRT route	Rail job multiplier – operation phase
	CAPEX of new Commuter rail	Rail job multiplier – construction phase
	CAPEX of rehabilitated Commuter rail route	
	O&M cost of Commuter rail route	Rail job multiplier – operation phase
Bus vehicles	CAPEX of ICE microbus new & replacement	
	O&M cost of ICE microbus	
	CAPEX of electric microbus	Electric bus multipliers – construction phase
	O&M cost of electric microbus	Electric bus multipliers – operational phase
	CAPEX of ICE minibus new & replacement	

	O&M cost of ICE minibus	
	CAPEX of electric minibus	Electric bus multipliers – construction phase
	O&M cost of electric minibus	Electric bus multipliers – operational phase
	CAPEX of ICE bus new & replacement	
	CAPEX of electric bus	Electric bus multipliers – construction phase
	O&M cost of electric bus	Electric bus multipliers – operational phase
Rail vehicle	CAPEX of LRT new & replacement	Rail job multiplier – construction phase
	O&M cost of LRT	Rail job multiplier – operational phase
	CAPEX of HRT new & replacement	Rail job multiplier – construction phase
	O&M cost of HRT	Rail job multiplier – operational phase
	CAPEX of diesel commuter rail new & replacement	Rail job multiplier – construction phase
	O&M cost of diesel commuter rail	Rail job multiplier – operational phase
	CAPEX of electric commuter rail new & replacement	Rail job multiplier – construction phase
	O&M cost of electric commuter rail	Rail job multiplier – operational phase
	CAPEX of bus charging infrastructure	Rail job multiplier – construction phase
	O&M cost for bus charging infrastructure	Rail job multiplier – operational phase
Cycling infrastructure	CAPEX of cycling infrastructure	Cycling job multiplier – construction phase
Private vehicles	CAPEX of ICE passenger automobiles & taxis new & replacement	
	O&M cost of ICE passenger automobile & taxis	
	CAPEX of EV passenger automobiles & taxi	EV job multipliers – construction phase
	O&M cost of EV passenger automobile & taxis	EV job multipliers – Operational phase
	CAPEX of ICE LDT new & replacement	
	O&M cost of ICE LDT	

|		
	CAPEX of electric LDT	EV job multipliers – construction phase
	O&M cost of electric LDT	EV job multipliers – Operational phase
	CAPEX of ICE MDT new & replacement	
	O&M cost of ICE MDT	
	CAPEX of electric MDT	EV job multipliers – construction phase
	O&M cost of electric MDT	EV job multipliers – Operational phase
	CAPEX of ICE motorcycle new & replacement	
	O&M cost of ICE motorcycle	
	CAPEX of electric motorcycle	EV job multipliers – construction phase
	O&M cost of electric motorcycle	EV job multipliers – Operational phase

B.2.2 Transport expenditure modelling structure

The transport expenditures were calculated within a bespoke modelling structure to project the costs the Green Recovery scenario developed in Pathways. The primary driver of transport expenditure projections were the passenger trips by mode and fuel type in 2021 and 2030 according to the Green Recovery scenario, as shown in Figure B.2.2 schematic below. Note that the model was initially designed to calculate jobs across more aspects of the transport sector, however only sustainable transport expenditure have been utilised for this analysis.

The scenario projection was combined with baseline passenger trip data from Pathways and other city transport profiling data collated separately, to estimate infrastructure capacity and number of vehicles by mode and fuel type in 2030. The baseline city profiling data covered infrastructure and vehicle data. Baseline infrastructure data consisted in figures for the length of road, segregated BRT and rail infrastructure[13] covering the city area only. Baseline vehicle data consisted in figures for the number of transport vehicles and rolling stock to match those within the Pathways model, which included passenger vehicles, passenger microbuses, minibuses, standard buses, BRT buses; as well as data on rail rolling stock.

Additional inputs to the model were the cost benchmarks broken down by new, rehabilitation, replacement and O&M costs benchmarks related to the public transport infrastructure and vehicle data, as well as useful life assumptions, so as to estimate the total public transport expenditures between 2021 and 2030. Costs were estimated on an annual basis to fully capture the O&M and replacement costs occurring over time.
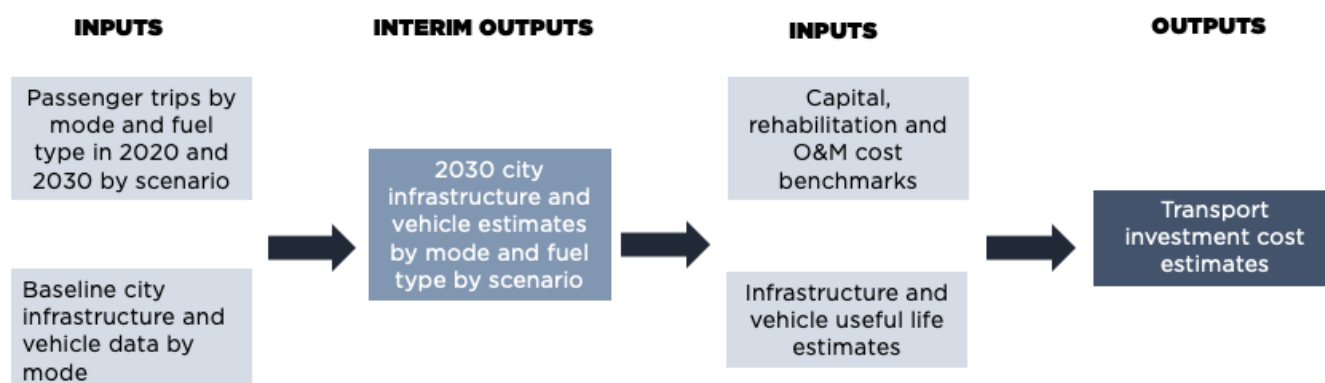
The following is an example calculation of how the expenditures were estimated for expansion of Light Rail Transit in a city under the Green Recovery scenario. In the given city, the 2021 and 2030 light rail transit (LRT) passenger trips were 225 million and 279 million respectively, indicating an increase of 24%. According to research, it was found that the current length of light rail transit in the city is 100 km. As a result, it was estimated that in 2030, the LRT rail infrastructure would increase according to the passenger trip expansion of 24%, to 124 km. The cost benchmark for new LRT infrastructure was 49 million USD per km and as result, expansion of the LRT was estimated to cost 1.2 billion USD.

There was one exception to this method: calculating the fleet of electric buses needed for Jakarta's Green Recovery scenario. Due to difficulty in gathering accurate data about current fleet utilization (annual passenger-trips per bus) and the relatively low utilization from estimates, the modelling assumes a custom bus utilization figure for Jakarta's Green Recovery scenario. Milan's current bus utilization rate was used as it is among the best of the five model cities and assumed achievable.

B.2.3 Key sources of transport data

The key sources of data for the projection of public transport investment costs to 2030 are shown in the table below alongside a summary of the main data collated from these. These represent common sources of data across the six cities analysed. Additional bespoke data was also collected and has been recorded within each model city's calculation workbooks.

Table B-3 Key sources of data used in transport investment cost projections

Source	Data Collected
Pathways model	Passenger trips in baseline year and 2030 by mode share and fuel type under the BAU and Green Recovery scenarios

International Energy Agency (IEA)14	Investment cost benchmarks for rehabilitation and O&M costs of rail infrastructure split by eight regions.
Institute for Transport and Development Policy (ITDP)15	Investment cost benchmarks for new segregated BRT corridors, LRT and HRT infrastructure as well as associated rolling stock split by high- and low-income country.
United Nations Environment Programme (UNEP)16	Investment cost benchmarks for new and O&M costs of Internal Combustion Engine and Battery Electric buses.
	Investment cost benchmarks for new and O&M costs and charger density multipliers of electric buses charging infrastructure.

B.2.4 Summary of key assumptions and limitations specific to transport

The following presents key assumptions and limitations specific to the approach and data collected for the calculation of transport investment costs across the cities. These are shown together given that a major source of uncertainty stem from assumptions. Note that limitations already mentioned in Section B.1.2 General limitations and recommendations for further development, were not repeated. .

- The cost of adoption of fuel-efficient private transport and transit modes was not estimated given evidence that fuel efficient vehicles based on the same powertrain (akin to the same fuel) do not carry a substantial price premium. Fuel efficiency gains can stem from conversion to different powertrains (e.g. petrol to diesel) however, as indicated below the investment cost analysis did not reach this level of granularity.
- The costs of reinforcing the grid due to increase in electrification of buses were not included. This would require further research into the baseline grid infrastructure of cities.
- BRT infrastructure was costed on the basis of introducing segregated BRT routes. It is noted that this is not always the case and alternatives may involve fewer costs.
- The cost of buses and rolling stock were based on a typical example of the vehicle type e.g. average passenger automobile. In reality, costs differ between models and brands; and preferences for these may vary according to the locality.
- Rail infrastructure costs were based on observed costs in typical conditions, i.e. not accounting for unusual terrain requiring tunnels or other atypical infrastructure.
- The cost of fossil fuel powered buses was based on a single cost for Internal Combustion Engine (ICE) vehicles although in reality vehicle costs differ between different input fuels e.g. diesel and gasoline. Additionally, a separate cost was not considered for vehicles run on biodiesels.

C   Part C: Methodology of employment estimates

Calculation of employment estimates was derived from work undertaken by Vivid Economics to generate employment multipliers for C40s analysis to quantify the climate and employment potential from undertaking a green recovery in cities. Employment multipliers are ratios that describe the relationship between investment within a particular sector and the number of jobs that particular investment creates.

For Interventions in Johannesburg, Milan and Houston this was a wider piece of work exploring job creation potential across multiple sectors. The relevant transport elements are presented below. For full details on the wider job creation work please see LOOK UP NAME OF DOCUMENT

C.1   Key definitions and parameters of the study

This section describes the parameters of the city-level employment effects study, looking at the definitions of the set of interventions evaluated, the cities analysed, and the data sources used.

C.1.1 Interventions modelled

Cities will use a wide range of climate-positive economic recovery strategies to respond to the disruption from the pandemic. Vivid Economics' work does not look at all of these interventions, instead we have prioritised the activities that best balance local job creation with mitigation and adaptation outcomes.

Twenty two interventions were selected from the longer list of 168 following a multi-criteria analysis. This shortlisting process considered the following criteria:

- Relevance – interventions were assessed on the basis of whether they were likely to be of high interest to city-level decision makers in the six cities considered in this study, as well as the larger set of C40 cities and urban areas in countries where C40 cities are located;
- Materiality – interventions were selected where they were likely to make a significant impact on a city's emissions and adaptation to climate impacts.
- Uniformity – given the relatively high-level assumptions required to model the impacts of these interventions at scale, these interventions were assessed as being most similar across different cities (compared to highly bespoke planning and project level interventions);

For the purposes of the Future is Public Transport COP briefing we selected the six interventions related to transport. The numbers of jobs quoted within the briefing are those from the three actions directly related to the expansion of public transport, namely BRT network, electric buses and commuter rail

The table below shows how we have defined the six transport interventions for the purposes of this study.

Table C-1 Definitions for priority interventions

Intervention	Definition
Bus Rapid Transport (BRT) network	Investment in buses and transport infrastructure improvements for a city-wide BRT network.
Electric buses	Cost of buying EV buses for public transport network, does not include investment in EV charging infrastructure in bus depots.
Cycling infrastructure	Construction and maintenance of cycle paths for safer use for cyclists - to encourage more active transport.
Electric vehicle infrastructure	Cost of investing in vehicle charging points for personal and commercial vehicle usage (does not include electricity costs)
Electric vehicles	Investment into private electric vehicles for household use.[6]
Commuter rail	Rail for transport services (not including freight); in London and Jakarta further subdivided between commuter rail and urban LRT.

Source: Vivid Economics

C.1.2 Pilot cities

The wider study on jobs focused on six pilot cities: Houston (USA), Miami (USA), Rome (Italy), Milan (Italy), Cape Town (South Africa), and Johannesburg (South Africa). These six were selected as a pilot for the employment multiplier modelling technique used in this study, but the approach has been designed flexibly so it can be applied appropriately to additional cities.

For the transport briefing we selected the cities of Houston, Milan and Johannesburg   to provide a geographical range of cities, selecting those that are likely to have higher levels of investment in transport. We then chose additional cities of London and Jakarta based on their strategic importance to the Future is Public Transport Campaign.

C.1.3 Sectors modelled

The I3M model assesses economic impacts through analysis of relationships between different sectors in the economy, using a Social Accounting Matrix for each country considered. This framework demonstrates expected impacts across an economy if an external shock increases or

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[6] Note this profile has been built off a cost base for electric cars, but we expect that the same multiplier could be equally applied to investments in other electric personal vehicles such as electric motorcycles.

decreases spending in one constituent sector. The sectors used in the I3M approach follow the Eora classification[7], with 26 sectors as shown in Table C-2 below:

Table C-2 I3M (Eora26) sector classifications

Number	Sector Name	ISIC Rev.3 correspondence
1	Agriculture	1, 2
2	Fishing	5
3	Mining and Quarrying	10, 11, 12, 13, 14
4	Food & Beverages	15, 16
5	Textiles and Wearing Apparel	17, 18, 19
6	Wood and Paper	20, 21, 22
7	Petroleum, Chemical and Non-Metallic Mineral Products	23, 24, 25, 26
8	Metal Products	27, 28
9	Electrical and Machinery	29, 30, 31, 32, 33
10	Transport Equipment	34, 35
11	Other Manufacturing	36
12	Recycling	37
13	Electricity, Gas and Water	40, 41
14	Construction	45
15	Maintenance and Repair	50
16	Wholesale Trade	51
17	Retail Trade	52
18	Hotels and Restaurants	55
19	Transport	60, 61, 62, 63
20	Post and Telecommunications	64
21	Financial Intermediation and Business Activities	65, 66, 67, 70, 71, 72, 73, 74
22	Public Administration	75
23	Education, Health and Other Services	80, 85, 90, 91, 92, 93
24	Private Households	95

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[7] Lenzen et al. (2013). Building EORA: a global multi-region input–output database at high country and sector resolution. https://www.worldmrio.com/pdf/LenzenEtAl_2013_BuildingEora_ESR.pdf

25	Others	99
26	Re-export & Re-import	

C.2   Investment profiles for modelled interventions

This section describes how we created profiles for each of the interventions above, and how these inputs feed into the I3M model to create city-specific employment multipliers. The employment multipliers created through this approach have been created to estimate the effect of investing 1 million USD in either capital expenditure (capex) or operating expenditure (opex). Users can select the level of investment expected in each city to assess the expected impact of a particular size of investment.

C.2.1 Creating intervention profiles

For each of the 22 shortlisted interventions, we compiled a bespoke profile that captures how this intervention interacts with a standard national economy. This follows the input-output logic of the I3M model: increasing spending in one sector of the economy will create knock-on effects in others, following the relationships defined in a country's social accounting matrix. I3M models these relationships to measure not only the direct employment impacts of the intervention, but the indirect employment created in other sectors as a result of the increased spending and induced impacts from consumption across the economy.

To create a 'shock' to the model, we need to understand the sectors which will benefit from increased spending on a particular intervention. This is what we estimate in an intervention profile, an example of which is shown below.

Table C-3 shows how capital and operational expenditures are split among sectors of the economy for a typical BRT intervention.

Table C-3 Example intervention profile for a BRT intervention

Bus Rapid Transport (BRT)		
Data source	Social, environmental and economic impact of BRT systems (2013), EMBARQ at World Resources Institute (WRI) Data drawn from BRT in Johannesburg	
Opex-capex ratio	2.9%	
Lifetime of each phase	Construction = 2 years Operation = 19 years	
Sectoral expenditure	Capex	Opex

	Transport Equipment	49%	Transport Equipment	94%
	Construction	49%	Construction	6%
	Financial Intermediation and Business Activities	1%	-	-
	Public Administration	1%	-	-

C.2.2 Inputting interventions into I3M

Each intervention is defined with a profile like the one in Table C-3 based on a standard cost assumption (e.g. USD 1 million), then I3M processes this additional spending through the economy using the ratios defined above. The I3M is a Leontief multiplier input-output model, therefore outputs include structured changes in sectoral final demand and any direct changes on employment.

Inputs to the model first split capital and operating expenditures according to the opex-capex ratios. Investments are defined such that capital expenditure is modelled equally in each construction year, for example on a $1m capital spend taking two years to complete, the model will split the $1m capital spend into $0.5m in year 1 and $0.5m in year 2. Total opex will similarly be split over the entire years of operation. Model users can define the value of opex separately from the input values of capex.

These capital and operating expenditures are then input as shocks in different sectors following the ratios defined in the profile. Following the example of a BRT project above, an annual capital expenditure of $1m, for example, would divide among $0.49m on transport equipment, $0.49m on construction, $0.01m on business activities, and $0.01m on public administration. We can then estimate direct employment impacts of this spending by dividing the resulting increase in output from these shocks between the average balance of capital and labour inputs in each sector[8]. We use this to measure the direct employment effect by dividing the proportion of spending going on labour by the average wage in that sector. This gives a total direct employment effect, and the same logic applies for both capital and operational expenditure.

I3M analyses the relationships between sectors to estimate the indirect effects of an increase in spending in one sector. If spending increases in construction, for example, then construction companies will have to buy more inputs from their suppliers. This increased spending on intermediate goods will also have a knock-on effect on employment in these supplying sectors, as increased demand for intermediate goods requires more labour to create these goods. I3M uses a social accounting matrix (SAM) approach to model these relationships, and so can help to measure indirect employment effects. A SAM captures the interdependence that exists within a socio-economic system, including between sectors, households and government, and outflows related to trade. This gives a more accurate estimate of the 'knock-on' impacts of an investment than an input-output approach. The SAM shows how increased activity in one sector influences economic activity in other sectors, while also factoring in relationships with consumers and

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[8] Using national capital-labour ratios for each sector from the Eora database

governments. The added nuance of consumers, government, and trade relationships makes the SAM approach a more accurate one than a standard input-output table.

I3M can also model the third tier 'induced' effects on employment that occur because of the general increase in spending across the economy. Induced impacts capture the consumption spending from workers impacted by (i.e. employed by) the direct and indirect shocks to the economy. With additional wages flowing to workers in these sectors, they are expected to consume more goods in the local economy, creating additional economic activity. Increases in demand will follow the pattern of spending from an average household. For the first five years (reported as 'short term' impacts), investment impacts are assumed to include induced effects, as these stimulatory impacts are of direct interest to policymakers shaping the recovery from the COVID-19 pandemic and related recession. 'Long term' induced impacts are also provided in case they are relevant for future analysis.

The I3M model has calculated these average annual job years multipliers using the method above, but the multipliers can be flexibly applied to different user inputs. The multipliers calculated from the model are output as average annual job years created per 1 million USD investment in either capex or opex, which can be loosely interpreted as the number of full time equivalent (FTE) jobs created by the intervention. This annual average job years multiplier gives a flexible unit for users to be able to choose the amount of capex or opex invested, and the length of time expected in the construction and operational lifetimes.

C.2.3 Data sources for intervention profiles

I3M can produce employment multipliers for any intervention with properly defined investment profile. To calculate robust employment multipliers, we therefore need to have reliable sources for these cost profiles. This sub-section shows the data sources used to cost each intervention defined in Table C-1 above.

For each intervention we have created an intervention profile that reflects the costs we expect from that kind of intervention. Table C-4 below shows the results of our data gathering exercise for the transport interventions, showing the average capital costs, operating costs, and project lifetimes associated with each intervention. Breakdowns of both capital and operating costs are provided for each intervention in Appendix (i), along with descriptions of the sources from which we have collected this data. Note that the approach for estimating expenditure (capital and O&M costs) per intervention is detailed in Section B; in some cases the costs were based on those collated by Vivid Economics were used, but not all.

Some interventions use a 'generic' profile that can apply regardless of which city is implementing the intervention. The benefit of this approach is that this creates a generalisable framework that can apply scale up and include other cities beyond our six priority cities for this study.

We have collected city-specific information for other interventions that we believe are less generalisable across the six cities in the analysis. Sometimes costs for interventions can vary significantly from city to city, and you can see these costs in the table below. We have collected this country-specific information for each of the adaptation activities.

C40 reviewed the sources underpinning each intervention for relevance, accuracy, and coherence with other C40 tools and analyses. The table below contains information on the final sources selected, and the cost information the source provides for input to I3M. The major point of revision of sources between the first iteration of the model and the complete version was to make the sources more specific to the locations and context in which interventions would take place. In particular, country-specific profiles were created for all adaptation interventions. Sources were reviewed for recency, accuracy of case study to the intended intervention use, reliability of the source, and completeness of data for I3M inputs. Sources were preferred that had a single source for each of the capex and opex sector assignments, capex and opex unit costs, and project lifetimes.

Table C-4 Intervention sources and cost profiles for each shortlisted intervention

Intervention	Intervention sub-category	Source	Description	Units	Capex (unit, USD)	Opex (unit annual, USD)	Lifetime - construction (years)	Lifetime - operational (years)
Bus rapid transport (BRT)		(Carrigan et al., 2013)	Report with case study costing BRT in Johannesburg, South Africa.	$/km	21,561,011.50	630,962.12	2	19
Electric buses		(United Nations Environment Programme, 2018)	UNEP tool to estimate the potential cost, energy, and emissions savings of a shift to electric mobility	$/bus	365,653.51	12,163.68	1	20
Cycling		(Benni, Macaraig, Malmo-Laycock, Smith Lea, & Tomalty, 2019)	Web article describing the components and costs of selected bicycle infrastructure measures and selected cycling programs from 16 Canadian cities	$/km	74,220.39	34.84	1	25
EV Infrastructure		(Energeia, 2018)	Web article showing market study for Australian electric vehicles	$/kW	632.71	76.98	1	10
EV personal vehicles		(US Department of Energy, 2019)	Online calculator for vehicle costs in the USA, including electric vehicles.	$/car	31,058.46	2,260.55	1	10
Commuter rail		(US Department of Transportation, 2016)	Web resource showing rail costs for US cities rail infrastructure investments	$/km	3,560,715.05	10,682.15	2	25

C.2.4 Summary of I3M approach and assumptions

Vivid's Investment and Intervention Impact Model (I3M) has been applied to assess the impacts of investment in green solutions, as compared to counterfactual spending packages deployed by countries in response to the COVID-19 pandemic. The I3M model uses an input-output framework to estimate the short-term and long-term impacts of investments and other interventions. To define the inputs to the I3M model, the interventions are characterised in terms of changes to the final demand for the output of specific sectors within the Eora26 classification scheme.[9] The I3M modelling framework estimates a 'per unit' impact of each intervention, which is then multiplied by the total amount of investment allocated to the intervention.

There are three key points to note about how the interventions are input to the model as shocks:

1. The model is agnostic to whether the source of the expenditure is from public or private sector. It does not account for any multiplying effect government investment can have. The modelling compares the economic and environmental impacts of like-for-like investment. To illustrate this:
   a. the model analyses the expected cost of expanding solar generation, which could be borne by state-owned enterprises or private sector firms.
   b. the model analyses the costs of implementing energy efficiency improvements in the building sector – this type of intervention is often part-funded by government through subsidies.
2. Each of these interventions are treated in the same way: the total cost of the investment is modelled without regard to the source of the expenditure.
3. The spending profiles are developed from real world investment cases of representative projects from both national and international sources.

In addition, key economic assumptions underpinning the I3M framework:

- **Constant returns to scale as production is increased.** The empirical technology observed in the I/O table is assumed to be the same at any level of production.
- **Slack capacity.** There is enough underused capacity in the economy to scale up production without requiring additional investment. This assumption is considered reasonable and valid in the context of an economic downturn where capital utilisation rates are expected to be relatively low.
- **Fixed prices.** The model does not allow for price adjustments. This assumption is critical, as the model does not consider substitution effects between inputs, but rather assumes they will always be used in the same proportions. In the short run this is a reasonable assumption, yet in the longer run, prices will reflect the increase in demand through an upward movement.

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[9] https://worldmrio.com/eora26/. The modelling for the USA uses the IMPLAN data platform https://implan.com/

The modelling outputs can be compared to a number of different counterfactual scenarios to consider how employment impacts may exceed or fall short of business as usual investments. Previous applications have considered fossil fuel investments (e.g. petrol vs EVs), alternative government spending in similar sectors (e.g. roads vs public transit) or zero counterfactual, which implies that no alternative investment would have gone forward. For this analysis, we assume a zero counterfactual and all inputs will be provided as gross jobs rather than net. Comparisons can be made at a later stage using the inputs generated from this analysis – for example in the national analysis, green recovery interventions are compared similar investments in interventions aligned with business as usual practice.

For more technical details of the I3M approach, please refer to Appendix (ii).

C.3   Localising employment effects

This section describes how these multipliers can estimate localised impacts in the six pilot cities. This section will also discuss the data needed to create these localised profiles and provides a general framework that could be applied to recreate this analysis to include further cities.

C.3.1 Approach for localising impacts

To estimate the extent to which the interventions create local employment opportunities within the city, we scale the multipliers to a city-specific level. The approach described in section 2.1 above primarily yields employment multipliers at a national level. This is because the SAMs used in the I3M model are nationally defined (with an exception for the USA cities, where Impact Analysis for Planning (IMPLAN) data allows a city-specific SAM to be constructed and used in the I3M). We need to scale national outputs to understand the balance of jobs created in the city compared to jobs created elsewhere in the country. Our 'scaling' approach varies depending on whether the multipliers are for direct, indirect or induced effects of a city-level intervention. Note that for USA cities, the city-level data availability is high enough to produce city-specific direct, indirect, and induced multipliers directly, without having to assume that 100% of direct national jobs are created in the city itself. This is not true for the Italian and South African cities. For other cities, the approach was as follows:

- **Direct jobs** – For all cities but Houston, we assume that a discretionary proportion of the direct jobs modelled from I3M (i.e. national, excluding imported inputs) will be created in the local area. This proportion can vary depending on factors such as the size of a sector within a city compared to national average, in terms of final demand of the products required to deliver the intervention. For an intervention that requires input from the agriculture sector, for example, while it is unlikely that there will be a substantial number of farmers within a given city, the actual 'agriculture' product demanded in most of these interventions is often landscaping or landscaping products. Cities will be more likely to be able to source these products within the city itself, and so agriculture may have a higher proportion of direct jobs captured. The choice on which proportion to apply is left to the discretion of the cities themselves, and section 4.3 below includes a suggested breakdown of proportions by sector which cities may wish to use as a starting point.
- **Indirect jobs** – There are two approaches to scaling indirect jobs based on data availability:

- o **Low data availability** – Scale the total number of indirect jobs created by the sectoral share of jobs in the region of the intervention. If a city region has 40% of the national share of employment in manufacturing, for example, and we know that an intervention will indirectly produce 10 jobs nationally in the manufacturing sector, then we estimate that the city will receive 4 out of those 10 manufacturing jobs. The I3M output will show the number of jobs in each sector that an intervention is expected to create. From separate regional employment data we understand how much of each sector's jobs we would expect to see in the region. For this study, we follow this approach for South Africa. This approach assumes that demand for intermediate goods in a city region will follow the same profile as the national average, and this may not be the case – likely serving as a low threshold.

   Due to resource and time constraints, London and Jakarta used an even simpler method, scaling city-level indirect jobs to the share of the city GDP's within national GDP. For example, London with 22% of national GDP is assumed to be home to 22% of indirect jobs. As above, this is likely a low threshold for the share of indirect jobs attributable to the city

- o **High data availability** – In Italy, we have access to local input-output tables which means we can see the share of local demand (in GVA) for a sector's inputs that is currently fulfilled by local suppliers, compared to the proportion fulfilled by national or international suppliers. This gives a more robust assessment of regional employment impacts, as it captures specific local supply-demand activity, compared to the 'low-data' assumption above that local demand will follow the national average, which does not capture any proximity bias that is likely to exist in some sectors.
- ● **Induced jobs** – The approach for estimating city-level induced employment multipliers will follow the same scaling approach as for indirect jobs, reflecting the assumption that induced demand is completely correlated to direct and indirect employment (e.g. those workers will consume where they are employed). Note that national induced job multipliers are calculated separately to indirect jobs following the methodology described in

C.3.2 Data requirements for localising impacts

We have scaled the results from the I3M model using city-specific data on economic activity. The scaling depends on the granularity of data available for the six cities, we have assessed data availability in Table C-5

Table C-5 Data availability comparisons for localising employment impacts

Data availability	Cities	Data source and sector impacts
High data	Houston	Direct integration into I3M (57+ sector detail for city regions and 'other US.' This data comes from IMPLAN, with latest data available for the year 2019. The counties available for Houston are: Harris County, Austin County, Brazoria County, Chambers County, Fort Bend County, Galveston County, Liberty County, Montgomery County, Waller County
Medium data	Milan	Integration of high-level local shares from 14 sectors in 2019 EUREGIO database to I3M framework for city region and 'other Italy.' The city region for Milan is Lombardy. EUREGIO sectors are mapped against the Eora26 sectors for comparison between different cities.
Low data	Johannesburg	City-level data collected from the Labour Dynamics Survey from Statistics South Africa (Quarterly employment statistics – province level microdata). National and city-level employment estimates are averaged between annual totals of 2019 and 2020 sectoral employment. The region for Johannesburg is 'City of Johannesburg.'

Source: Vivid Economics

In the USA, IMPLAN data[10] was used for the IO tables, enabling analysis at both the national level and a state level. IMPLAN data has a much more detailed sectoral disaggregation than the Eora26 sectors used in the I3M outputs. To allow easier comparison against other cities, these more detailed sectors are mapped back to the Eora26 sector definitions. The unit of analysis in the IMPLAN SAMs is the value of transactions taking place between sectors and institutions in USD[11], and the latest data availability is from 2019.

The IMPLAN counties used for each US city align to the larger metropolitan area for each city, known as Metropolitan Statistical Agencies (MSAs) in the US. These counties correspond to the Miami-Fort Lauderdale-Pompano Beach and Houston-The Woodlands-Sugarland MSA.

For Italy, we localise employment impacts using data from the EUREGIO database, which models supply and use tables for all NUTS2 regions across the European Union.[12] This database models inputs, outputs, and value add in 14 sectors, including estimates of interregional trade, using 2018 EUR. These 14 EUREGIO classified sectors (Thissen et al., 2018) and then mapped against the Eora26 sectors for inputting to I3M. Against the EUREGIO sector S2 (Mining, quarrying, and energy supply), for example, we map Eora sectors 3 (Mining and quarrying) and 13 (electricity, gas and water). These supply and use tables allow us to understand how much of demand for goods and services can be supplied locally, and how much will be supplied nationally. To take a stylised

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[10] IMPLAN Group, LLC. IMPLAN Data 2020. Huntersville, NC. IMPLAN.com

[11] The most recent currency year reported in the IMPLAN portal is 2021 USD for Houston. Both data use 2019 interactions to calculate the input-output relationships.

[12] https://data.jrc.ec.europa.eu/dataset/84356c3b-104d-4860-8ce3-075d2eab37ab

example, if we see that 40% of construction services (S9 - construction) are supplied locally within NUTS2 region Lombardy (for Milan), then we estimate that 40% of the indirect construction jobs created from an intervention in Milan will be classed as local employment impacts. In this example, workers from other regions will supply the remaining 60% of additional construction jobs. For Rome, the Lazio region is the corresponding NUTS2 region.

In South Africa we estimate local employment effects by scaling multipliers by the provincial employment shares from national statistics.[13] The approach takes the proportion of average of national employment in a given sector in two years (2019 and 2020) and the average of city-level employment in that sector in the same two years (2019 and 2020). For example, on average in 2019 and 2020, 10.6% of manufacturing jobs in South Africa are found in City of Johannesburg. We assume, therefore, that 10.6% of the indirect manufacturing jobs created from an intervention will be created in Johannesburg itself. This is likely to underestimate the actual indirect effect, as local manufacturers in Johannesburg are probably more likely than the national average to fulfil local demand. This is a less robust estimate than for the US and European cities, due to lack of detailed input-output modelling for the South Africa cities. It is, however, a scalable approach that can be used for other cities and countries that may also have limited data.

C.3.3 Potential adaptations to city-level direct job creation

Section C.3 above introduced the idea of scaling the national level direct jobs multipliers based on a discretionary proportion of the capacity of the sector in that city to create these additional jobs. The table below shows an indicative assessment of how cities may wish to scale these direct jobs per sector. Two key questions underpin the assessments in this table: "how much of the spending will cities be able to find local firms/branches to buy from? And: how much of that spending will go towards operations in the city?"

Users should note that the proportions shown below are based off a rapid high-level assessment conducted for these interventions, and so they should only be used as a starting point for consideration of direct jobs impacts in cities, rather than a definitive view on how well each city can create direct jobs in these sectors. Each city will have different characteristics, and so we would encourage each city to judge the sectoral employment creation potential based on their own expertise of the economic geography. Additionally, the suggested scaling factor for sectors is based on an interpretation of the activities associated with each in the shortlist of interventions modelled – these should not be interpreted as applicable to all activities in these sectors, only those in the modelled interventions. The sector scaling factors have been assessed as follows:

- Sectors most likely to involve inputs from outside the city region received the rating of 'low' implying a 25% adjustment to direct multipliers for a local estimation.
- Other manufacturing/processing sectors received a 'medium' rating and a 75% adjustment reflecting the likelihood of involving some firms with a local presence, but with need for additional inputs from outside the city region.

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[13] Using the Labour Market Dynamics Survey available from Statistics South Africa

- The remaining sectors score a 'high' rating and a 90-100% adjustment, except for agriculture which involves some specialized landscaping components, it is likely that local firms could credibly supply all additional demand in these sectors.

Table C-6 Proposed direct job localisation multipliers

EORA Sector	Local direct jobs presence assumed	Indicative localization multiplier
Agriculture	High	90%
Mining and Quarrying	Low	25%
Textiles and Wearing Apparel	Medium	75%
Wood and Paper	Low	25%
Petroleum, Chemical and Non-Metallic Mineral Products	Medium	75%
Metal Products	Medium	75%
Electrical and Machinery	Medium	75%
Transport Equipment	Medium	75%
Construction	High	100%
Maintenance and Repair	High	100%
Transport	High	100%
Post and Telecommunications	High	100%
Financial Intermediation and Business Activities	High	100%

Source: Vivid Economics

C.4   Integrating equity into employment estimates

This section focuses on how we integrate demographic factors into the employment analysis.

An assessment of the equity impacts of modelled interventions was delivered using local labour market demographics to characterise modelled jobs against key equity considerations including gender, race, and age. This analysis adds to the value of estimating labour impacts, enabling cities to identify how climate action could support, or hinder, efforts to develop a more equitable workforce.

This workstream was composed of three main steps:

- Step 1. Constructing a robust database capturing employment demographic profiles (gender, race and age) by occupation, combining this data with sector level

employment by occupation. Data sources range between national, regional and city specific depending on availability for each country.

- Step 2. Mapping jobs impacts profiles from modelling outputs country sector categories. We map the job impacts from each intervention onto relevant economic activity sectors for the US, Italy, and South Africa.
- Step 3. For each intervention, we created an employment impact profile outlining the gender and race breakdown for US and South African cities, and the expected gender and age distribution for cities in Italy. This profiling draws on data collected and results from the modelling outputs and overlays them onto sector profiles broken up into demographics by occupation.

The following sections expand in more detail each of the steps outlined above.

C.4.1 Constructing a workforce equity database for each country

We compiled data on gender and race for the US and South African cities and age and gender for Italian cities. This data compiles equity by type of occupation, linking this to sector level employment by type of occupation:

- For Houston the data focus on creating sector specific profiles which describe the divide in employment by race and gender. Data is from the American Community Survey (ACS) 5 year estimates to compile sector employment by occupation, and occupation by gender at the county level. Data from Miami-Dade County in Florida is used for Miami, and data from Fort Bend County, Harris County and Montgomery County in Texas is used for Houston. For occupation employment split by major race categories, data is from ACS 1 year estimates (Table C-6). This is also the source for data on Hispanic or Latino origin, which is analysed as a separate ethnic category additional to race.[14]
- For Milan sector profiles focus on gender and age. We use regional data from Eurostat which captures employment by gender and age by 10 NACE Rev. 2 sectors. To sense check the regional data, we use city specific data on employment by gender and age (which is not disaggregated at the sector level and therefore cannot be used as the primary source).
- For Johannesburg as with US cities, sector profiles focus on gender and race. Data availability for sector specific employment demographics is available at the city level from the quarterly Labour Force Survey, disaggregated by 10 industries.

Occupations are determined by country-specific classification systems that are consistent across sectors. US data uses the Standard Occupational Classification (SOC) System, which has 10 major categories. Italian data is disaggregated by the International Standard Classification of Occupations (ISCO-08), which also has 10 major categories. South African data is presented using the South African Standard Classification of Occupations (SASCO), which has 9 major categories

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[14] Ethnic data overlays race data, such that people of any racial category can also be of Hispanic or Latino origin. The disaggregated race categories will describe 100% of the population; the ethnicity data should be interpreted separately, such that the proportion of the population that is Hispanic or Latino should not be added to the proportion of the population that is White, Black or African American, Asian or some other race.

and is based on ISCO-08. To give an example of the level of disaggregation in these classification systems, managers form their own occupational category while services and sales workers form another.[15]

Table C-7 presents the data sources which underpin the sector profiles for employment demographics.

Table C-7 Data sources to compute employment demographics by occupation by sector

Country	Data	Data source	Geographical unit	Description of measurements for each
USA	Sector employment by occupation	U.S. Census Bureau, 2015-2019 American Community Survey 5-Year Estimates	County level[16]	Persons over 16 employed by the 14 NAICS sectors split by the 5 Standard Occupational Characteristics (SOC) occupation types: ● Management, business, science and arts occupations ● Natural resources, construction and maintenance occupations ● Production, transportation and material moving occupations ● Sales and office occupations ● Service occupations
	Occupation employment by gender	U.S. Census Bureau, 2015-2019 American Community Survey 5-Year Estimates	County level	Persons employed in each of 5 SOC occupation types, split gender (women, men)
	Occupation employment by race	U.S. Census Bureau, 2019 American Community Survey 1-Year Estimates	County level	Persons employed in each of 5 SOC occupation types, split by major race and ethnicity categories[17] ● White ● Black or African American ● Hispanic or Latino ● Asian ● Some other race

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[15] The 10 major categories of ISCO-08 are the following: armed forces occupations; clerical support workers; craft and related trades workers; elementary occupations; managers; plant and machine operators and assemblers; professionals; services and sales workers; skilled agricultural, forestry and fishery workers; and technicians and associate professionals. (https://www.ilo.org/wcmsp5/groups/public/---dgreports/---dcomm/---publ/documents/publication/wcms_172572.pdf)

[16] Data from Fort Bend County, Harris County and Montgomery County in Texas is used for Houston

[17] Note that the race categories were chosen to simplify the analysis and capture insights on the largest proportions of the population. For example, not a large proportion of the population is classed as 'American Indian', so this category is not summarised in the analysis output.

Italy	Sector employment by occupation	Eurostat – [Employment by occupation and economic activity (from 2008 onwards, NACE Rev. 2) - 1 000 [lfsq_eisn2]](#)	Country level	Persons employed in each of 10 International Standard Classification of Occupations (ISCO) 08 occupation types, split by 21 NACE Rev. 2 sectors
	Occupation employment by gender	Eurostat – [Employees by sex, age and occupation (1000)](#)	Country level	Persons employed in each of 10 ISCO 08 occupation types, split by gender
	Occupation employment by age	Eurostat, [Employees by sex, age and occupation (1000)](#)	Country level	Persons employed in each of 10 ISCO 08 occupation types, split by the following age categories: ● From 15 to 24 years ● From 25 to 49 years ● From 50 - 74 years and over ● 75 years and over
South Africa	Sector employment by occupation	[South Africa - Quarterly Labour Force Survey 2020](#)	City (Johannesburg and Cape Town)	Employment per sector (10 sectors) split by occupation (10 occupations)
	Occupation employment by gender	[South Africa - Quarterly Labour Force Survey 2020](#)	City (Johannesburg and Cape Town)	Employment by occupation split by gender
	Occupation employment by race	[South Africa - Quarterly Labour Force Survey 2020](#)	City (Johannesburg and Cape Town)	Employment by occupation split by race (groupings include African/Black, Coloured, Indian/Asian, White)

Source: Vivid Economics

C.4.2 Mapping economic activity sectors

To create equity profiles of the modelled interventions, we map model outputs to the economic sector activities specific to each country's sector profiles constructed from Step 2. Outputs from the I3M model are disaggregated according to the Eora26 economic activity classification system. However, each country uses a different economic activity classification system to collect and present its labour and equity related data. US sector level statistics are reported according to NAICS 2017; for Italy, data is disaggregated according to NACE Rev. 2; and South African data is classified according to South Africa's SIC 7. All of these classification systems map back to the

UN's most recent version of ISIC from which it is possible to map aggregate sector categories back to Eora26.

The mapping path is described for each country below:

- United States – Employment demographics disaggregated by 271 NAICS 2017 subsectors (aggregated to 20 standardised NAICS 2017 sectors, as listed in Appendix 5) can be mapped onto Eora26 categories through the use of ISIC categories.[18]
- Italy – Data on gender and age per sector disaggregated by 10 NACE Rev. 2 categories (comprised of an aggregation of 21 standardised NACE Rev. 2 sectors, as listed in Appendix 5) can be mapped onto Eora26 categories through the use of ISIC categories.[19]
- South Africa – Sector specific demographics data is disaggregated by 10 categories based on 21 standardised SIC 7 sectors (as listed in Appendix 5) which can be mapped to Eora26 categories through ISIC tables.[20]

Appendix (iii) shows the correspondence of NAICS 2017, NACE Rev. 2 and SIC 7 to ISIC 4, which is the first mapping step needed to get to Eora26.

C.4.3 Developing job equity profiles for each intervention modelled

The intervention profiles developed mirror the information presented on employment impacts, breaking down the estimated impacts according to the demographics collected in Step 1. Each intervention profile for the cities outlines the sectoral breakdown of employment according to the structure that was used to develop the employment profiles, following the sectoral breakdown and Capex/Opex split.

Occupation-specific demographic data is applied to sector-specific occupation splits.
Demographic characteristics vary across occupations, and occupations are distributed differently across sectors. Demographic data is linked to occupation type, and then aggregated at the sector level according to sector employment by occupation. That is, a demographic profile is constructed by applying occupation-specific demographic data to the proportions of occupation types within each sector.

Estimated jobs supported by climate action are assumed to have the same occupation split as their corresponding sectors. For example, 100 estimated jobs supported in a sector comprised of 20% managerial occupations and 80% production occupations are disaggregated into 20 managerial jobs and 80 production jobs.

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[18] US corresponding tables: NAICS 2017 to ISIC 4 to ISIC 3.1 to ISIC 3 to Eora26.

[19] Italy corresponding tables: NACE 2 to ISIC 4 to ISIC 3.1 to ISIC 3 to Eora26.

[20] South Africa corresponding tables: SIC 7 to ISIC 4 to ISIC 3.1 to ISIC 3 to Eora26

Table C-8 Example with hypothetical data on equity expanded intervention profile for BRT

Bus Rapid Transport (BRT)					
Intervention description	Brief description of the distribution of jobs supported across sectors, linking to the specific interventions.				
Total direct jobs	1110				
Sectoral employment	**Capex**				
	Sector	Total jobs	Gender – women employed	16- 25 employment	50-65 employment
	Transport Equipment	450	250	100	100
	Construction	450	200	100	100
	Financial Intermediation and Business Activities	5	4	3	3
	Public Administration	5	4	3	3
	Opex				
	Sector	Total jobs	Gender – women employed	16- 25 employment	50-65 employment
	Transport Equipment	100	20	30	30
	Construction	100	20	30	30
Indirect job impacts					
		Total jobs	Gender – women employed	16- 25 employment	50-65 employment
	Indirect jobs	1000	400	550	100

Note: The data presented in the table is hypothetical and used to illustrate how the intervention profiles have been created

Source: Vivid Economics

C.5   Assessment of limitations and areas for further research
C.5.1 Sense-checking of employment multipliers

The analysis described in this section reflects a number of innovative approaches to developing employment multipliers for green recovery interventions. As such, external reviewers were encouraged to focus on employment multipliers and a series of sense-checks were undertaken to test the validity of the multipliers. The table below describes key sense-checks carried out and the response or findings from these.

Table C-9 Summary of key comments and sense-checks carried out on employment multipliers

Sense-check	Finding
Sense-check #1: spot-checks were carried out on the share of Green Recovery jobs created and supported out of total employment in city to check these were plausible.	The share of annual jobs represented a range from 0.4% to 6.3% of total employment of the cities or metropolitan regions depending on the geographical boundary of the employment analysis.
Sense-check #2: comparison of national employment multipliers to other studies	For Italy, national multipliers were compared to those within the National Energy and Climate Plan of Italy and another study[21] and found to be similar. For USA, certain operational multipliers were found to be anomalous based on comparison with an employment study relating to transportation[22] and the investment profiles were revised. For South Africa, the national multipliers were cross-referenced with a UNIDO study[23] and found to be a similar scale. In general, differences in jobs multipliers are driven by 1) wage levels, 2) structural differences in payments to labor and 3) import intensities. These largely explain the differences in scale of multiplier between the three countries.
Sense-check #3: the total employment estimations per pilot city were compared against the other pilot city within the same country	It was found that there were reasonable explanations for any differences and these related mainly to scale of investment rather than the multipliers.
Sense-check #4: the race distribution within employment multipliers was compared to the city average	It was found that the race distribution in employment from the interventions analysed was similar to the distribution of the population as a whole

C.5.2 Limitations and areas for further development

The following list summarised areas that would benefit from further expansion and refinement based on identified limitations in the approach:

- Assessment of local shares of direct jobs by sector can be strengthened with location-specific analysis of economic activity and constraints
- Expansion and enrichment of country and city level social accounting matrices to reflect new sectors reflecting changing industrial practices and supply chain detail

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[21] https://www.fondazionesvilupposostenibile.org/wp-content/uploads/2019/04/Rilanciare-leconomia-e-loccupazione-in-Italia-2019.pdf

[22] https://jobstomoveamerica.org/resource/transforming-transit-realizing-opportunity/

[23] https://www.unido.org/news/global-green-growth-institute-and-unido-launch-green-growth-report-support-clean-energy-investments-and-jobs

- Extension of equity analysis to consider current and required skill levels of city workforce to support investments and mitigate any adverse impacts on the current workforce
- Improved use of city level supply and use tables, especially for Italy and South Africa, which rely on higher level regional GVA data for assessment of local impacts

D   Appendix (i) - Intervention investment profiles

Table D-1 Intervention profiles for transport interventions

| Intervention	Units	Capex (unit, USD)	Opex (unit annual, USD)	Construction - Lifetime (years)	Operational - Lifetime (years)	Opex/Capex Ratio	Construction sectors - implan	Construction sectors - EORA	Construction sectors - proportion	Operation sectors - implan	Operation sectors - EORA	Operation sectors - proportion
Bus rapid transport (BRT)	$/km	21,561,011.50	630,962.12	2	19	2.93%	Construction of new highways and streets	Construction	81.12%	Automotive repair and maintenance, except car washes	Maintenance and Repair	92.54%
							Heavy duty truck manufacturing	Transport Equipment	17.02%	Maintenance and repair construction of highways, streets, bridges, and tunnels	Maintenance and Repair	5.60%
							Architectural, engineering, and related services	Finacial Intermediation and Business Activities	1.04%	Business support services	Finacial Intermediation and Business Activities	1.87%
							Legal services	Finacial Intermediation and Business Activities	0.83%			
Electric buses	$/bus	365,653.51	12,163.68	1	20	3.33%	Heavy duty truck manufacturing	Transport Equipment	100.00%	Automotive repair and maintenance, except car washes	Maintenance and Repair	100.00%
Cycling	$/km	74,220.39	34.84	1	25	0.05%	Maintenance and repair construction of highways, streets, bridges, and tunnels	Maintenance and Repair	55.57%	Maintenance and repair construction of highways, streets, bridges, and tunnels	Maintenance and Repair	100.00%
							Other plastics product manufacturing	Petroleum, Chemical and Non-Metallic Mineral Products	13.77%			
							Architectural, engineering, and related services	Finacial Intermediation and Business Activities	20.00%			
							Other support services	Finacial Intermediation and Business Activities	10.67%			
EV Infrastructure	$/kW	632.71	76.98	1	10	12.17%	Construction of new power and communication structures	Construction	66.67%	Commercial and industrial machinery and equipment repair and maintenance	Maintenance and Repair	100.00%

							Power, distribution, and specialty transformer manufacturing	Electrical and Machinery	33.33%			
EV personal vehicles	$/car	31,058.46	2,260.55	1	10	7.28%	Automobile manufacturing	Transport Equipment	100.00%	Automotive repair and maintenance, except car washes	Maintenance and Repair	100.00%
Electric commuter rail	$/km	3,560,715.05	10,682.15	2	25	0.30%	All other transportation equipment manufacturing	Transport Equipment	54.62%	Commercial and industrial machinery and equipment repair and maintenance	Maintenance and Repair	100.00%
							Construction of new commercial structures, including farm structures	Construction	16.88%			
							Relay and industrial control manufacturing	Electrical and Machinery	6.51%			
							Other computer related services, including facilities management	Finacial Intermediation and Business Activities	0.21%			
							Data processing, hosting, and related services	Post and Telecommunications	1.09%			
							Other real estate	Finacial Intermediation and Business Activities	4.70%			
							Railroad rolling stock manufacturing	Transport Equipment	2.04%			
							Environmental and other technical consulting services	Finacial Intermediation and Business Activities	13.95%			

E   Appendix (ii) – Technical details of I3M approach

Vivid's Investment and Intervention Impact Model (I3M) has been applied to assess the impacts of investment in urban climate action. The I3M model uses an IO framework to estimate the short-term and long-term impacts of investments and other interventions. To define the inputs to the I3M model, the interventions are characterised in terms of changes to the final demand for the output of specific sectors within the Eora26 classification scheme.[24] The I3M modelling framework estimates a 'per unit' impact of each intervention, which is then multiplied by the total amount of investment allocated to the intervention.

I3M is an input-output modelling framework which can be calibrated to work with any IO data source. In this work, data for all countries except the US were drawn from the Eora Global Supply Chain Database. Individual country IO tables were aggregated to the Eora26 sector classification. Each IO table is a square matrix that represents the intermediate transactions between all sectors in the economy. In addition, the final demand of households, investment, government purchases and foreign countries for the output of all sectors is represented in the Final Demand block. Correspondingly, the primary inputs to sectoral production (labour, capital etc.) are represented in the Primary Inputs block. A simplified version of the table is represented in Figure E-1.

*Figure E-1   Simplified representation of a national Eora IO table*
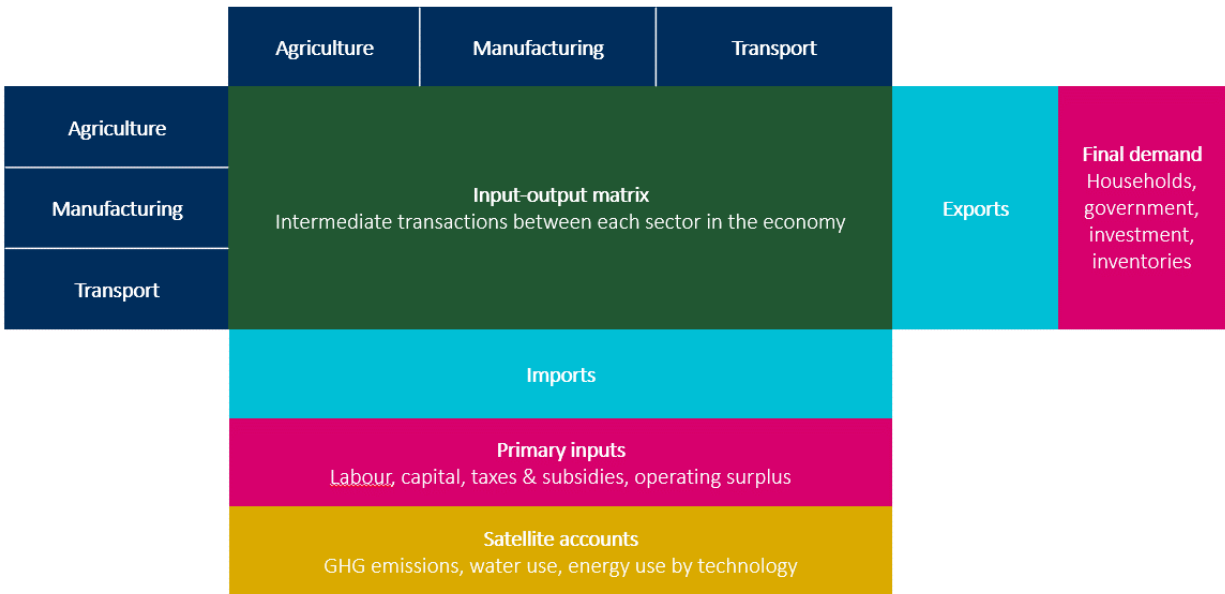
Source: Vivid Economics

I3M works by modelling the impacts of investments and other interventions as shocks to final demand in specific sectors. The flowchart in Figure E-2 shows how the IO table is used to calculate

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[24] https://worldmrio.com/eora26/. Modelling for the US uses the IMPLAN data platform https://implan.com/

the matrix of Leontief multipliers. Multiplying a shock vector (a change in final demand for every sector) by the Leontief matrix produces the increase in sectoral output needed to satisfy the increase in final demand. Relationships between sectoral output and variables such as GVA, employment and GHG emissions, determined from the satellite accounts of the Eora database, are used to calculate the impacts of the shock. The shock vector itself determines the 'direct' impacts, while the additional impacts on sectoral output are used to calculate the 'indirect' impacts.

Figure E-2   Representation of the I3M system
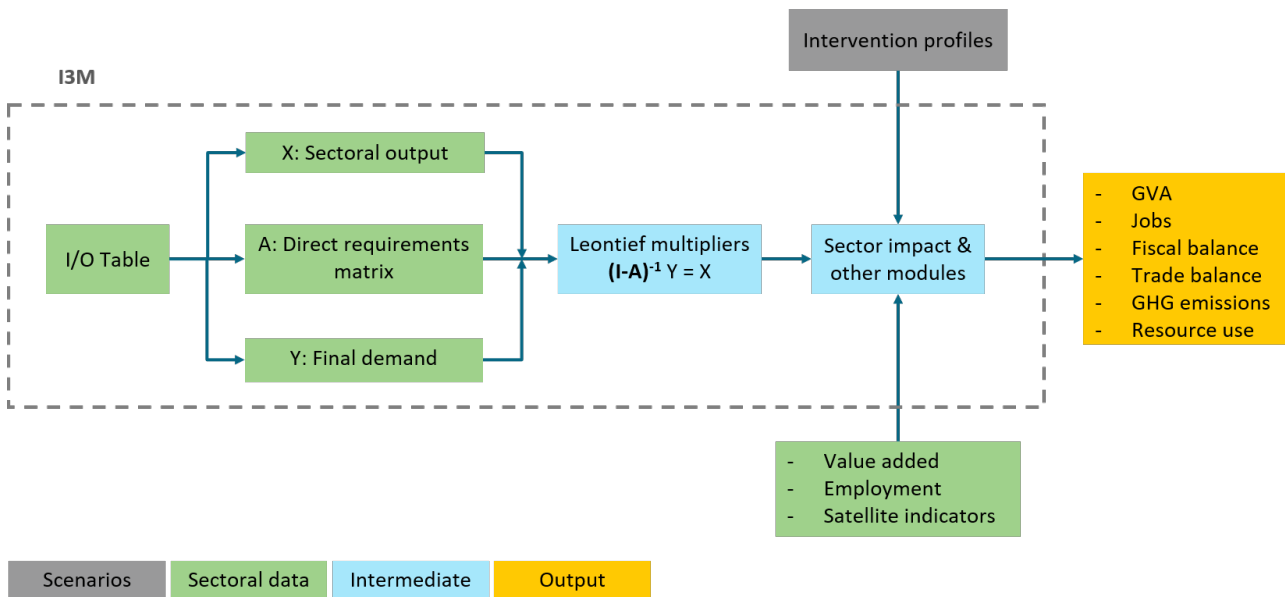
Source: Vivid Economics

Labour is a key input into production across the economy. The economic shock, as modelled by I3M, leads to increased demand for inputs both from the impacted sector and indirectly affected sectors. The increase in labour demand that results from this is expressed in FTE job years.

The impacts of interventions are shown as the annual impacts from the capital phase (capex). Additional jobs may be created over the operational phase (opex), and these are reported in the text. However, the financial investment considered in the analysis is purely the capital cost. To deliver the operational jobs and impacts, the investment needs to have a market to operate, or, where this is not the case, may need continued longer-term governmental support or a regulatory environment that enables the formation of this market. As these longer-term jobs fall outside of the immediate stimulus period, they are secondary to the analysis in this report, but they are impacts that are potentially of interest to a policy maker, and ensuring the continued operation of current investments beyond the immediate recovery is vital to ensuring their long run economic impact.

The analysis draws on real-world investment cases to translate the interventions into model inputs. Model inputs are the changes in expected demand for different sectors over time, which are captured in spending profiles for the 'investment' and 'operational' phases. The investment phase consists of capital expenditure, which are the costs of manufacturing, constructing, or

installing the technologies – such as installing a wind farm or building a power plant. Delivery of climate interventions is assumed to translate to capital expenditure. The 'operational' phase consists of operational expenditure, including on inputs (such as fuel) and maintenance.

There are three key points to note about the model:

1. The model is agnostic to the source of the expenditure and does not account for any multiplying effect government investment can have. The modelling compares the economic and environmental impacts of like-for-like investment. To illustrate this:

    a. the model analyses the expected cost of expanding solar generation, which could be borne by state-owned enterprises or private sector firms.

    b. the model analyses the costs of implementing energy efficiency improvements in the building sector – this type of intervention is often part-funded by government through subsidies.

2. Each of these interventions are treated in the same way: the total cost of the investment is modelled without regard to the source of the expenditure.

3. The spending profiles are developed from real-world investment cases of representative projects from both national and international sources.

F   Appendix (iii) – Sector mapping corresponding tables

Table F-1 shows the correspondence of NAICS 2017, NACE Rev. 2 and SIC 7 to ISIC 4 sector categories. This correspondence is the first step in mapping each country's economic activity classification system to Eora26, which is used for I3M model outputs. From ISIC 4 activities are mapped to ISIC 3.1 and subsequently to ISIC 3. From ISIC 3, there is a direct mapping to Eora26 sectors, as seen in Table C-2 in Section C.1.3.

Table F-1 Mapping of NAICS 2017, NACE Rev. 2 and SIC 7 to ISIC 4

NAICS 2017 – United States		NACE Rev. 2 – Italy		SIC 7 – South Africa		ISIC 4	
Sector	Sector description	Section	Section description	Section	Section description	Section	Section description
11	Agriculture, forestry, fishing and hunting	A	Agriculture, forestry and fishing	A	Agriculture, forestry and fishing	A	Agriculture, forestry and fishing
21	Mining, quarrying, and oil and gas extraction	B	Mining and quarrying	B	Mining and quarrying	B	Mining and quarrying
31-33; 81	Manufacturing; Other services (except public administration)	C	Manufacturing	C	Manufacturing	C	Manufacturing
22	Utilities	D	Electricity, gas, steam and air conditioning supply	D	Electricity, gas, steam and air conditioning supply	D	Electricity, gas, steam and air conditioning supply
22; 56	Utilities; Administrative and support and waste management and remediation	E	Water supply; sewerage, waste management and remediation activities	E	Water supply; sewerage, waste management and remediation activities	E	Water supply; sewerage, waste management and remediation activities
23	Construction	F	Construction	F	Construction	F	Construction

NAICS 2017 – United States		NACE Rev. 2 – Italy		SIC 7 – South Africa		ISIC 4	
42; 44-45; 81	Wholesale trade; Retail trade; Other services (except public administration)	G	Wholesale and retail trade; repair of motor vehicles and motorcycles	G	Wholesale and retail trade; repair of motor vehicles and motorcycles	G	Wholesale and retail trade; repair of motor vehicles and motorcycles
48-49	Transportation and warehousing	H	Transportation and storage	H	Transportation and storage	H	Transportation and storage
72	Accommodation and food services	I	Accommodation and food service activities	I	Accommodation and food service activities	I	Accommodation and food service activities
51; 54	Information; Professional, scientific, and technical activities	J	Information and communication	J	Information and communication	J	Information and communication
52; 55	Finance and insurance; Management of companies and enterprises	K	Financial and insurance activities	K	Financial and insurance activities	K	Financial and insurance activities
53	Real estate and rental and leasing	L	Real estate activities	L	Real estate activities	L	Real estate activities
54; 55; 81	Professional, scientific, and technical activities; Management of companies and enterprises; Other services (except public administration)	M	Professional, scientific and technical activities	M	Professional, scientific and technical activities	M	Professional, scientific and technical activities

NAICS 2017 – United States		NACE Rev. 2 – Italy		SIC 7 – South Africa		ISIC 4	
53; 56	Real estate and rental and leasing; Administrative support and waste management and remediation	N	Administrative and support activities	N	Administrative and support activities	N	Administrative and support service activities
92	Public administration	O	Public administration and defence; compulsory social security	O	Public administration and defence; compulsory social security	O	Public administration and defence; compulsory social security
61	Educational services	P	Education	P	Education	P	Education
62	Health care and social assistance	Q	Human health and social work activities	Q	Human health and social work activities	Q	Human health and social work activities
51; 71	Information; Arts, entertainment, and recreation	R	Arts, entertainment and recreation	R	Arts, entertainment and recreation	R	Arts, entertainment and recreation
44-45; 81	Retail trade; Other services (except public administration)	S	Other service activities	S	Other service activities	S	Other service activities
81	Other services (except public administration)	T	Activities of households as employers; undifferentiated goods- and services-producing activities of households for own use	T	Activities of households as employers; undifferentiated goods- and services-producing activities of households for own use	T	Activities of households as employers; undifferentiated goods- and services-producing activities of households for own use
92	Public administration	U	Activities of extraterritorial organisations and bodies	U	Activities of extraterritorial organisations and bodies,	U	Activities of extraterritorial organisations and bodies

NAICS 2017 – United States	NACE Rev. 2 – Italy	SIC 7 – South Africa	ISIC 4
		not economically active people, unemployed people etc	